

A Computational Two-Scale Approach to Nonlinear Analysis of Etherogeneous Composite Structures

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The paper investigates some fundamental issues and computational procedures for the multiscale approach to derive nonlinear constitutive relations for the finite element analysis of composite structures. In the last years the growing interest in modelling the nonlinear constitutive behavior of real composite materials has required the development of more and more sophisticated constitutive equations, in which several phenomenological failure mechanisms take place and interact each other. The increasing difficulties of handling a number of internal variables, which drive damage, plasticity, fracture, and the like mechanisms, either for the activation conditions, or for the evolution laws of all that interacting phenomena, make researchers wonder if the development of very complex phenomenological constitutive relations is really the best way to face the problem. A further point is that complex constitutive equations also require many material parameters to be identified for their physical meaning and experimentally quantified in value.

An emerging alternative approach is based on the direct observation of the material microstructure, and following a micro-structure finite element discretization, which basically corresponds to a computationally homogenization procedure, retrieve constitutive relations as the mean values overall material mechanical response. The nonlinear structural analysis based on this kind of approach requires a two-level (or two-scale) analysis [1, 2]. Namely, the material is represented in the form of a unit cell, in which a detailed description of its composition is reported.

At the material scale (micro-scale) the micro components are constitutively described by simple nonlinear phenomenological relations (like isotropic damage, J_2 plasticity and/or interface elements can be also introduced for modelling micro-debonding or microfractures) and a finite element analysis performed with the intent to derive incremental stress-strain response to be adopted for the analysis of the full structure (macro-scale), which as usual, is computationally analyzed by a standard finite element approaches.

The multiscale approach is nowadays a well developed branch of computational mechanics and in this paper some insight contributions are given as far as thermodynamic consistency is concerned. Some further details are given with regard to computational aspects of the practical and numerically efficient way to enforce periodic boundary conditions [3] for the finite element analysis of the Representative Volume Element (RVE) or Unit Cell.

The numerical application presented regards a specific 2-D plane-strain problem in which the structure is realized in a composite material formed by a matrix reinforced with transverse long fibers. The unit cell is reported in Fig. 1. For the microstructure finite element nonlinear analysis, the fibers are assumed always in an elastic state, the matrix is modelled as an elastic-plastic material and along the boundary between matrix and fiber a cohesive-frictional interface elements are adopted to model local fiber debonding failure modes. The size of the RVE is given as $V_E = L^2$ (for unit thickness), whereas the

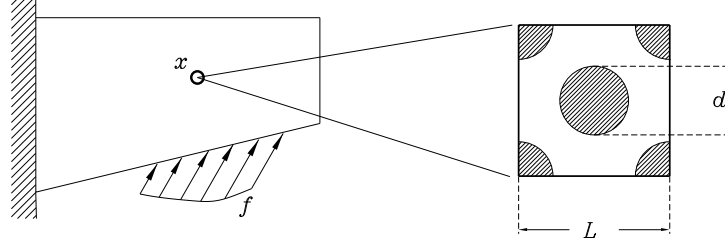


Figure 1: Composite structure (macro-scale) and Representative Volume Element (micro-scale)

fiber volume is $V_F = \pi d^2/2$, where d is the diameter of the fibers, which can be also expressed as $d = \alpha L$. The parameter α can reach a theoretical maximum limit value of $\alpha_{max} = 1/\sqrt{2}$ which correspond to the maximum fiber volume fraction of $f_{max} = \alpha_{max}^2 \pi/2 = \pi/4$. Considering as a parameter the fiber volume fraction it is shown the different structural behavior and the related structural and material failure modes.

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References

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